SPICE, 21st May 2026

Quantum materials:

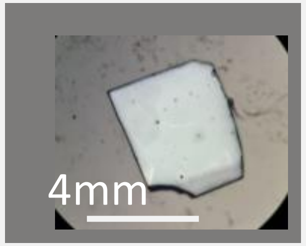
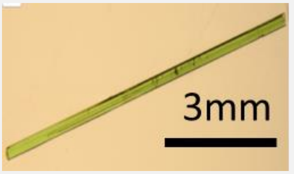
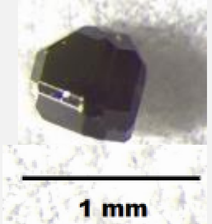
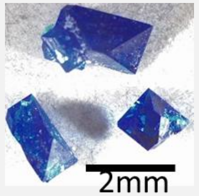
Spin Transport and Dynamics in Chiral Magnetic insulators

Dr. Aisha Aqeel

Emmy Noether Group Leader (DFG)

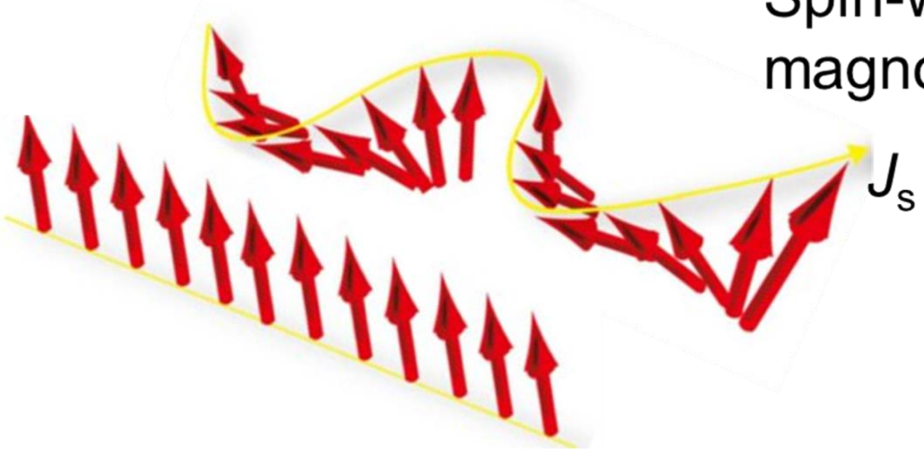
University of Augsburg

My group: Materials → structure → excitations → transport

Ferromagnets (Ferrimagnets)	Antiferromagnets		Altermagnets
			 
Cu_2OSeO_3	$CuSeO_3$	$SeCuO_3$	Cu_3TeO_6

GHz → THz

Spin-waves
magnons



Size: 4 mm - 1 cm

High quality

- ✓ No measureable twining
- ✓ **Ultralow magnetic damping** $\alpha = 10^{-4}$

Aqeel, et al., Phys. Status Solidi B (2022)

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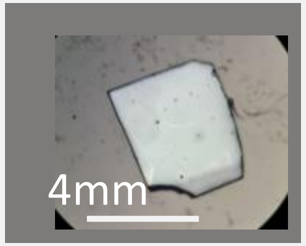
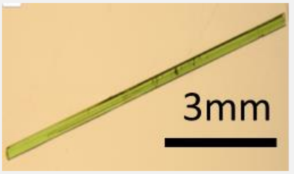
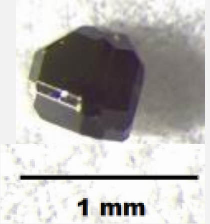
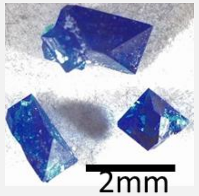


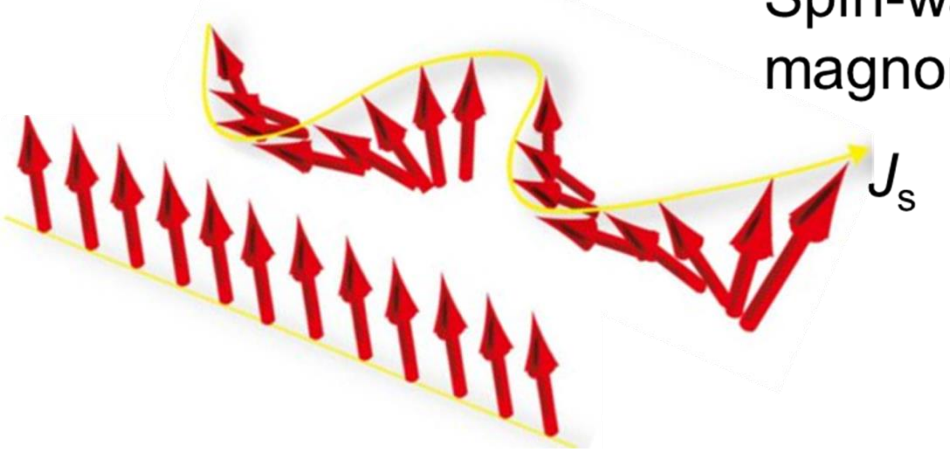






Cu_2OSeO_3 | $CuSeO_3$ | $SeCuO_3$ | Cu_3TeO_6

GHz → THz



Spin-waves
magnons

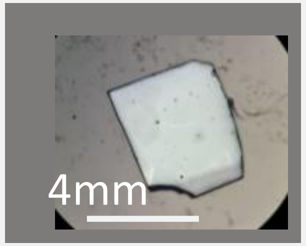
Unified spectroscopy–transport

- Magneto-transport access
- Broadband (40 MHz – 40 GHz)

1.5–300 K · up to 14 T · AC fields

My group: Materials → structure → excitations → transport

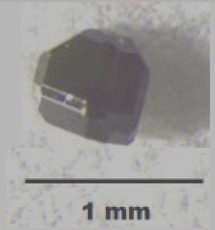
Ferromagnets (Ferrimagnets)	Antiferromagnets		Altermagnets

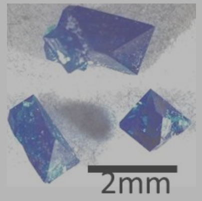


Cu_2OSeO_3

$CuSeO_3$

$SeCuO_3$





Cu_3TeO_6

GHz → THz

Unified spectroscopy–transport

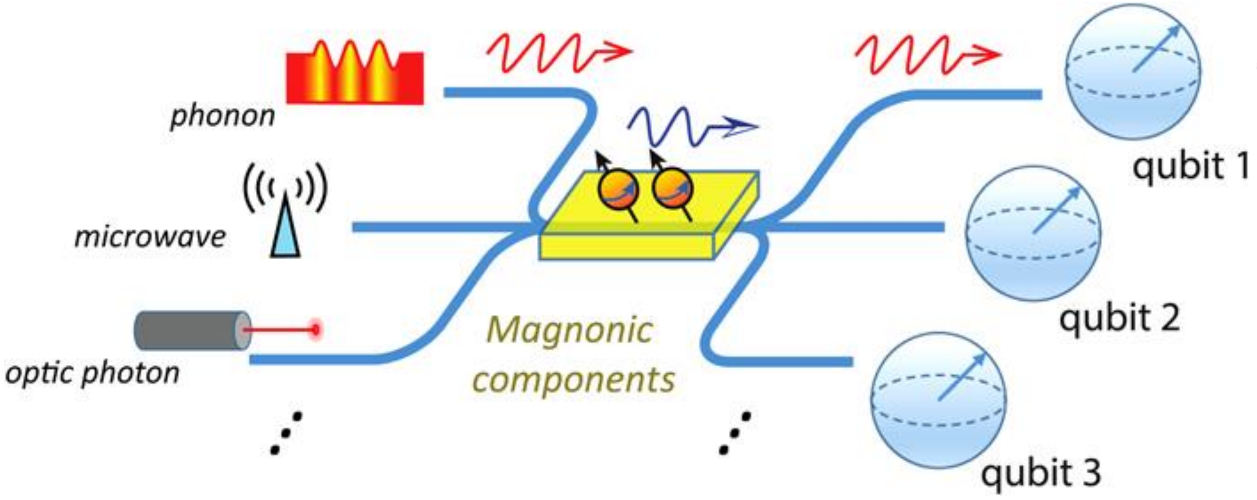
Magnetoresistance →

Magnons →

- Magneto-transport access
- Broadband (40 MHz – 40 GHz)
  1.5–300 K · up to 14 T · AC fields

Magnetic materials → **Quantum information**

Quantum transduction

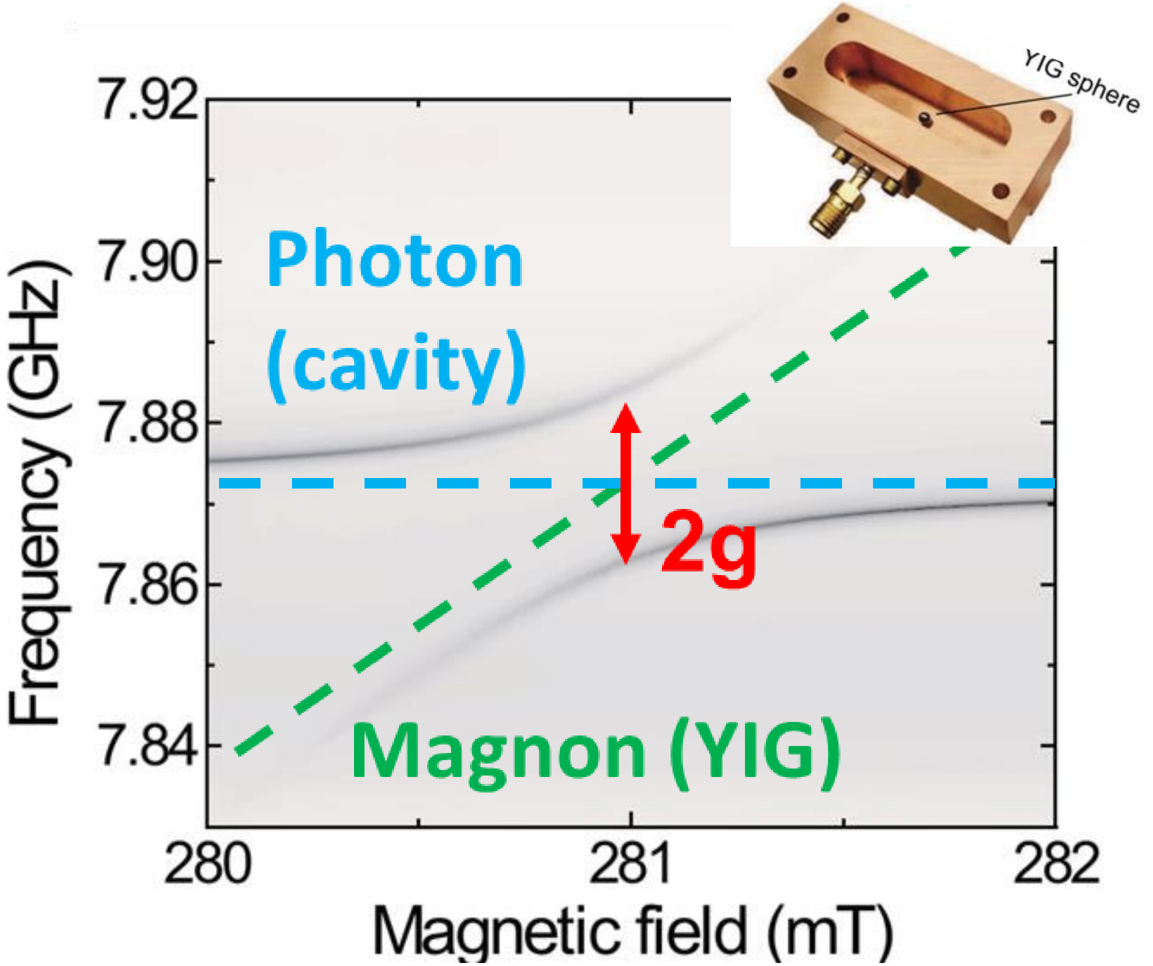


Coupling: dipolar interaction $E = \mu_0 \vec{M} \cdot \overrightarrow{h_{rf}}$

Cooperativity: $C = \frac{g^2}{k_m k_p}$

Strong coupling: $C > 1$ $g > k_m, k_p$

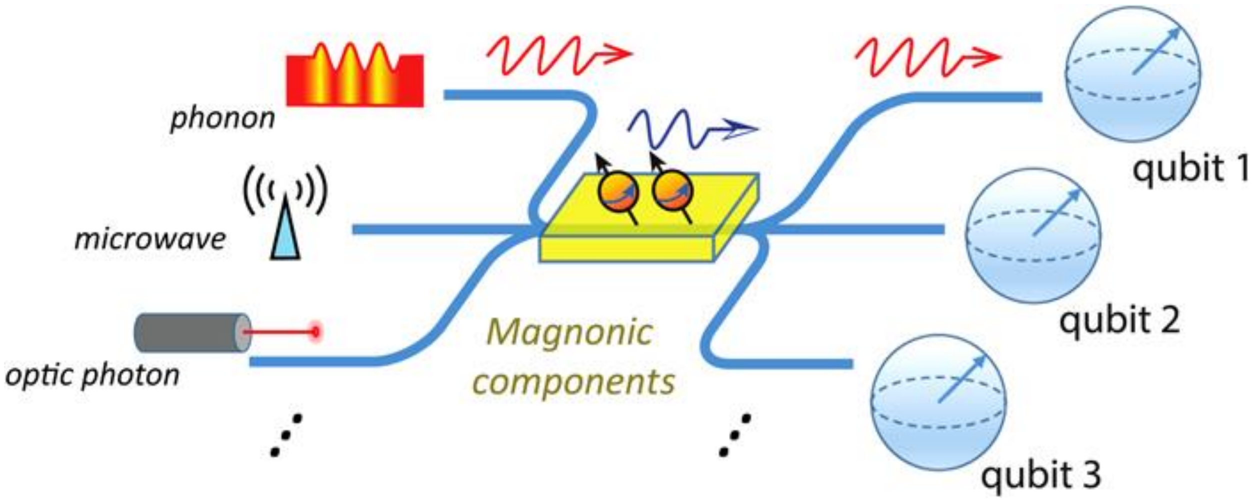
Y. Li, et al., *J. Appl. Phys.* 128, 130902 (2020)



X. Zhang, et al., Phys. Rev. Lett. **113**, 156401 (2014)

Magnetic materials → Quantum information

Quantum transduction



Challenge

1. Ultra low damping
2. Strong coupling

Benchmark low damping:

$\alpha \lesssim 10^{-5} - 10^{-4}$ (not at mk)

Yttrium Iron Garnet (YIG)

Need for new clean magnetic systems

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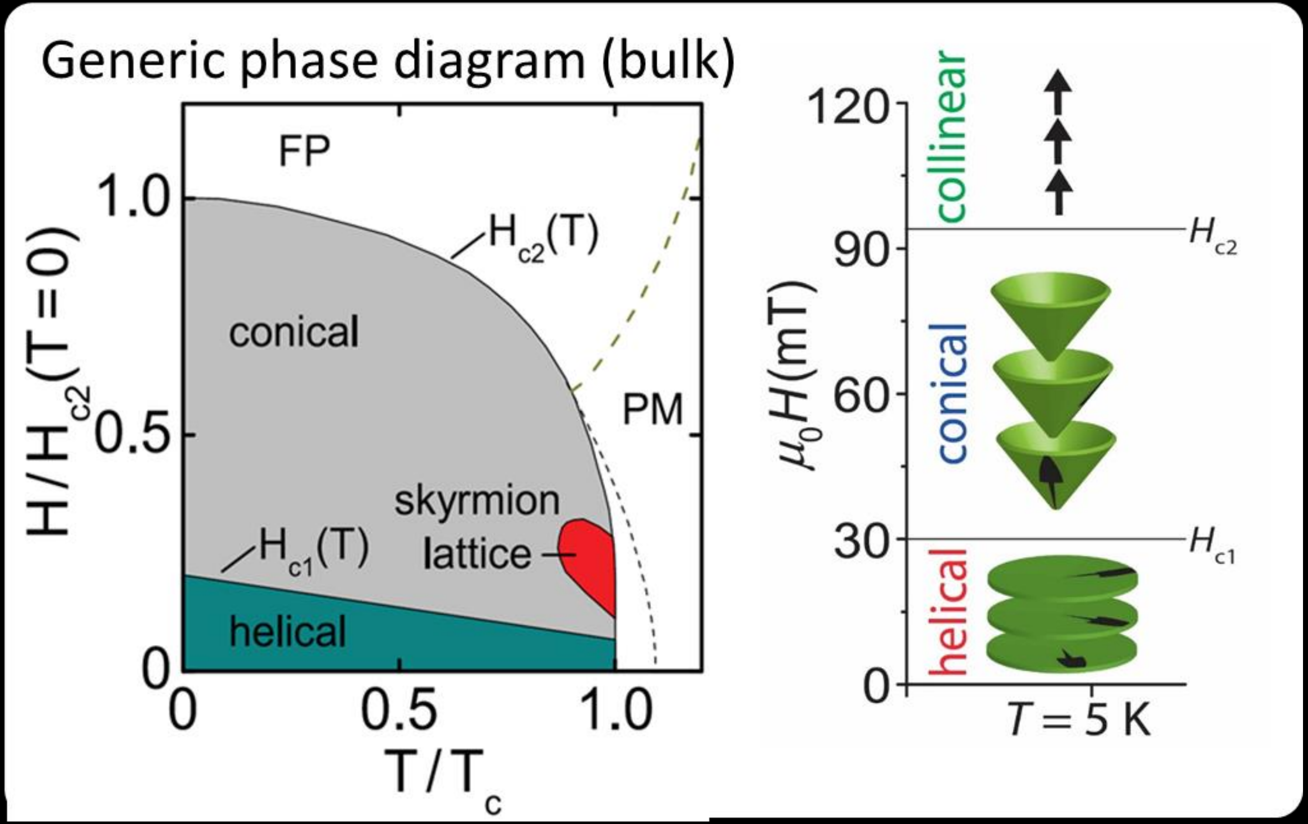
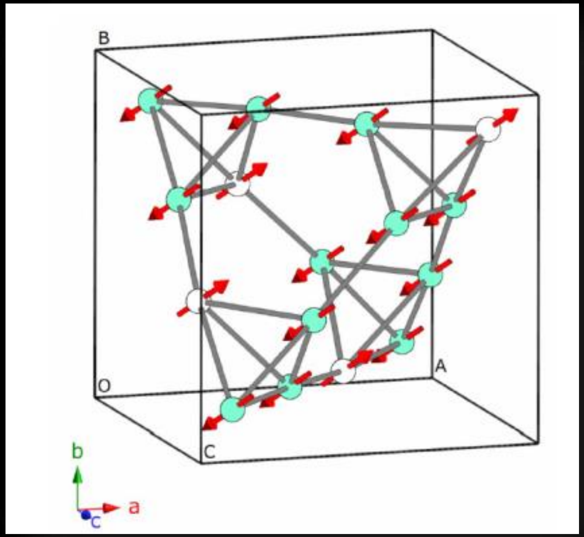
Chiral magnet: Cu_2OSeO_3 (Insulator)



Bos, et al., PRB **78** (2008)



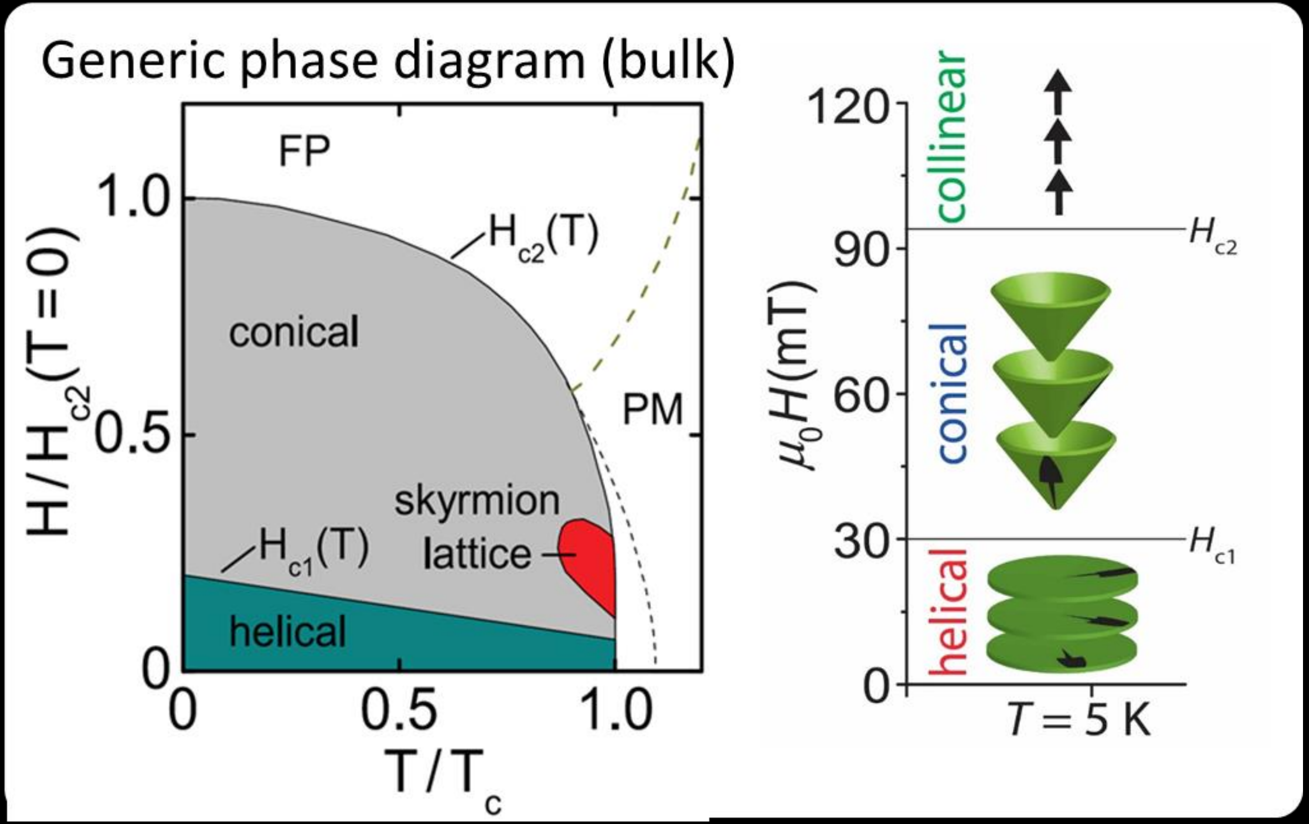
Non-centrosymmetric (chiral, $P2_13$)

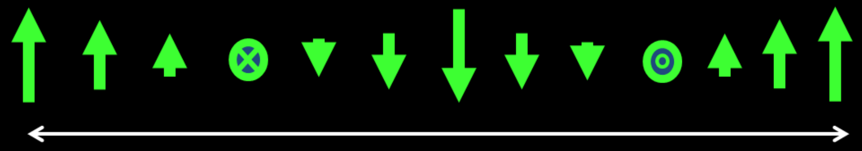
$T_c \approx 60\mathrm{K}$

$H_{c2} \approx 120\mathrm{mT}$ at 5K

Magnetic damping $\alpha \approx 10^{-4}$ at 5K

Chiral magnet: Cu_2OSeO_3 (Insulator)





$\lambda \approx 60\text{nm}$

Large Faraday rotation ~ 170 deg/mm

Magneto-optical susceptibility:

$\upsilon\,(540\text{nm}) \sim 10^4$ rad/T.m

$T_c \approx 60\text{K}$

$H_{c2} \approx 120\text{mT at } 5\text{K}$

Magnetic damping $\alpha \approx 10^{-4}$ at 5K

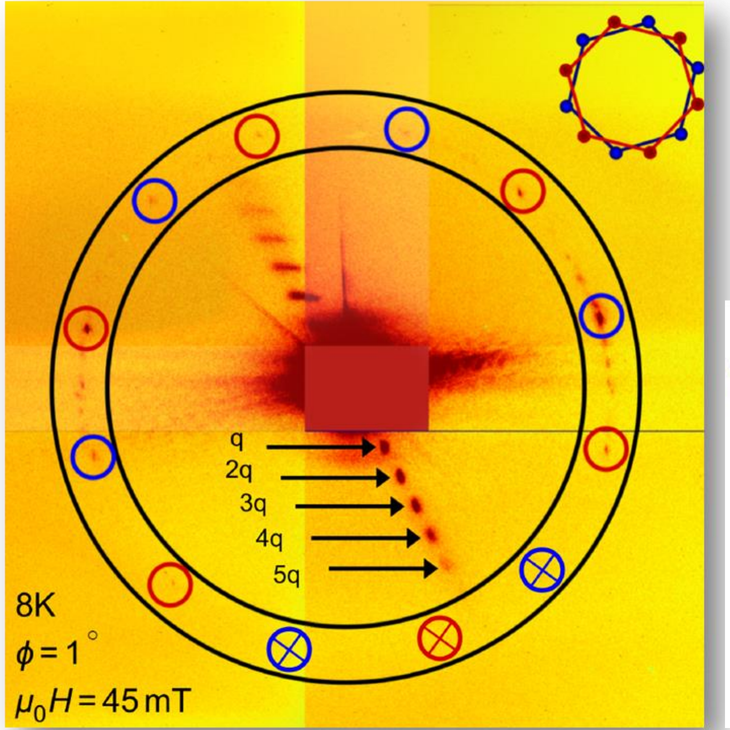
Versteeg,…Aqeel, *et al.*, Phys. Rev. B **94**, 094409 (2016)

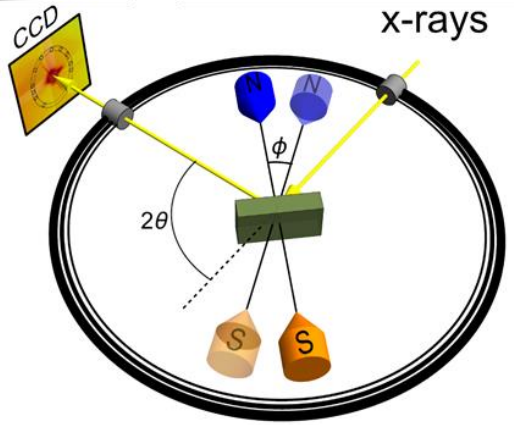
Aqeel, et al., Phys. Rev. B **103**, L100410 (2021)

Magnetic materials → **alignment & spatial spin structure**

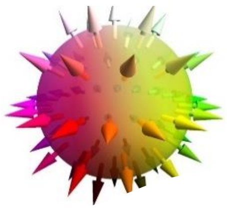
Mehboodi,..**Aqeel**, STAM (2025)

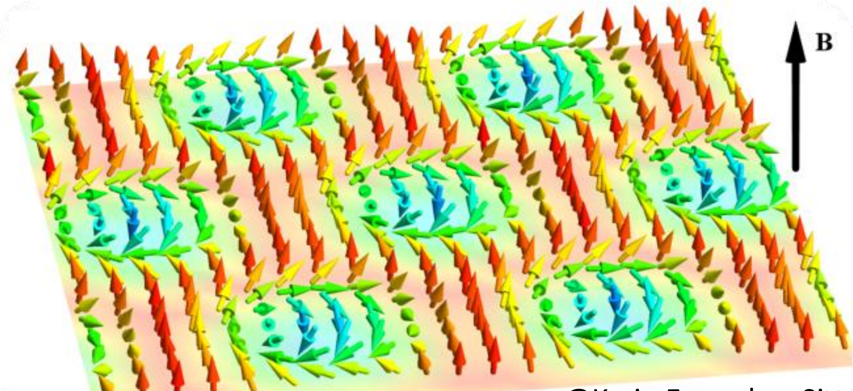
Skyrmion Lattice =
Magnetic Superstructure





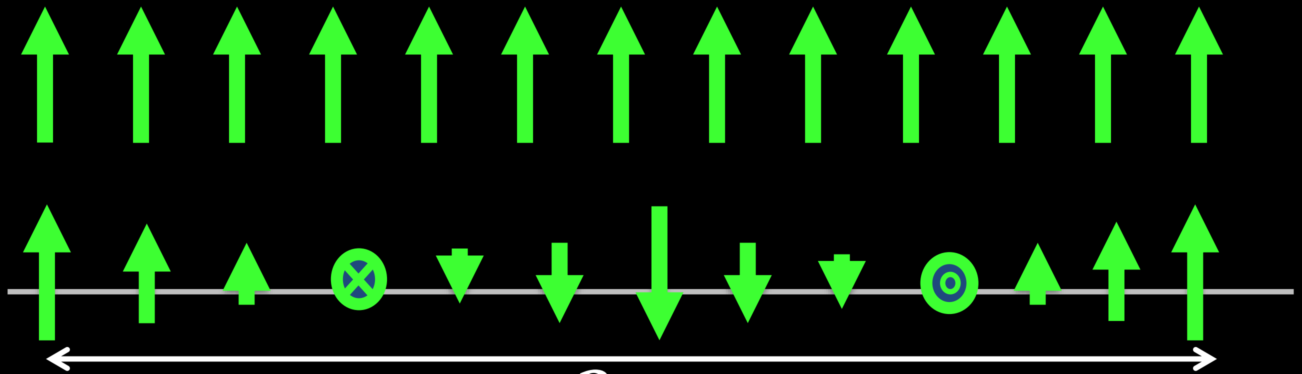
Periodic, but **non-uniform**
Breaks symmetry of uniform magnet





@Karin Everschor-Sitte

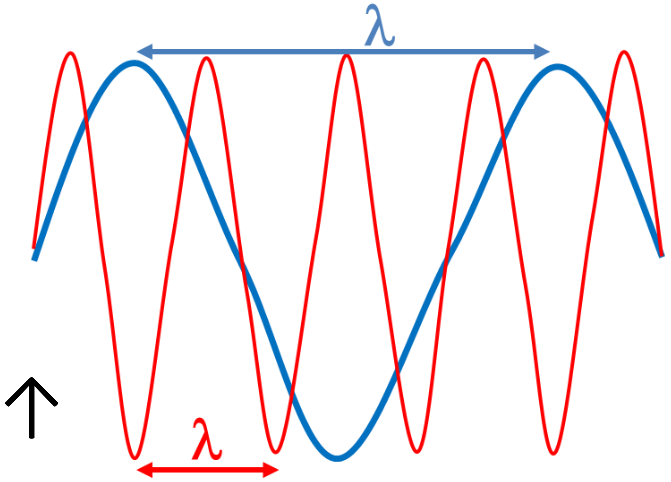
Cu_2OSeO_3 → **alignment & spatial spin structure**



$$\lambda \approx \frac{2\pi}{|Q|}$$

Theoretically:

$f \propto \mathbf{q} \propto \mathbf{1/\lambda}$



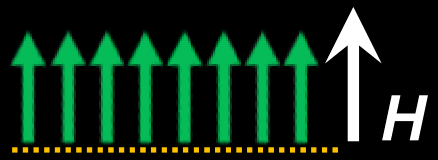
Spirals due to Structural chirality : $\lambda\uparrow, f\downarrow$

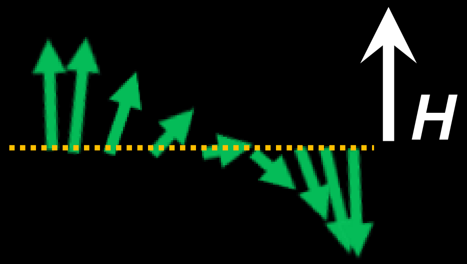
no frustration (like ferromagnet)

Spirals in AFM (Centrosymmetric, Frustrated): $\lambda\downarrow, f\uparrow$

Chirality introduces new degrees of freedom beyond magnetization.

Magnetic materials → **alignment & spatial spin structure**





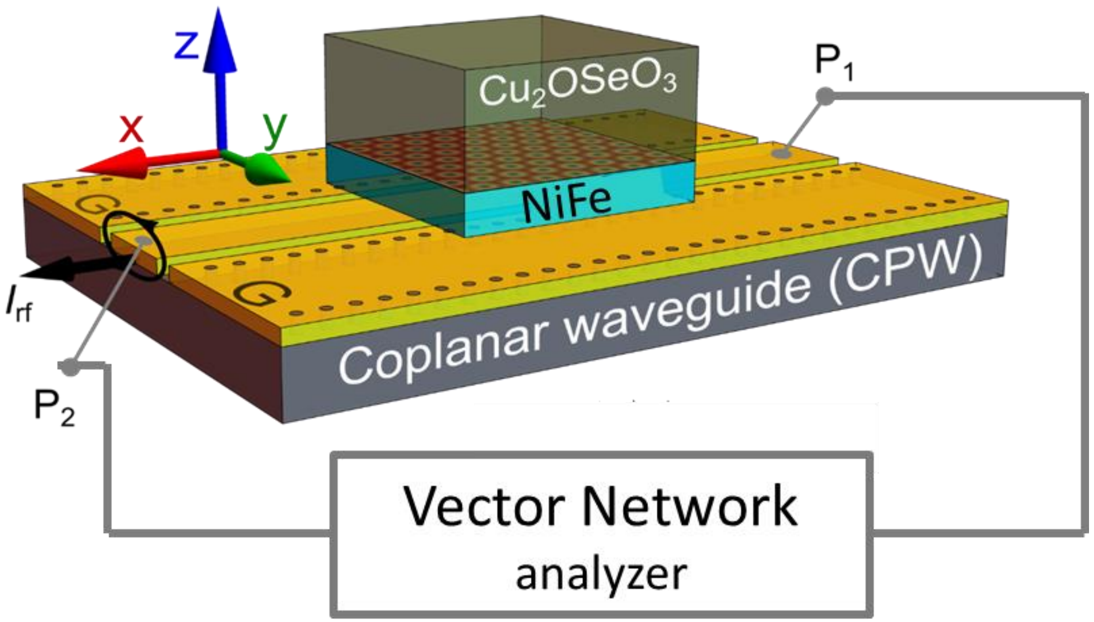
System	**Ferromagnets**	**Antiferromagnets**	**Noncollinear (spiral)magnets**
Frequency	Low (GHz)	High (THz)	High (GHz-THZ)
Detection/ Manipulation	Easy	Challenging	Easy
Magnon modes	1	2	≥ 1

Broadband spectroscopy of spin dynamics

Direct access to $\chi''(\omega)$ across MHz - GHz frequencies

Accessing the excitation spectrum directly

Sample-on-chip geometry (CPW + heterostructure)



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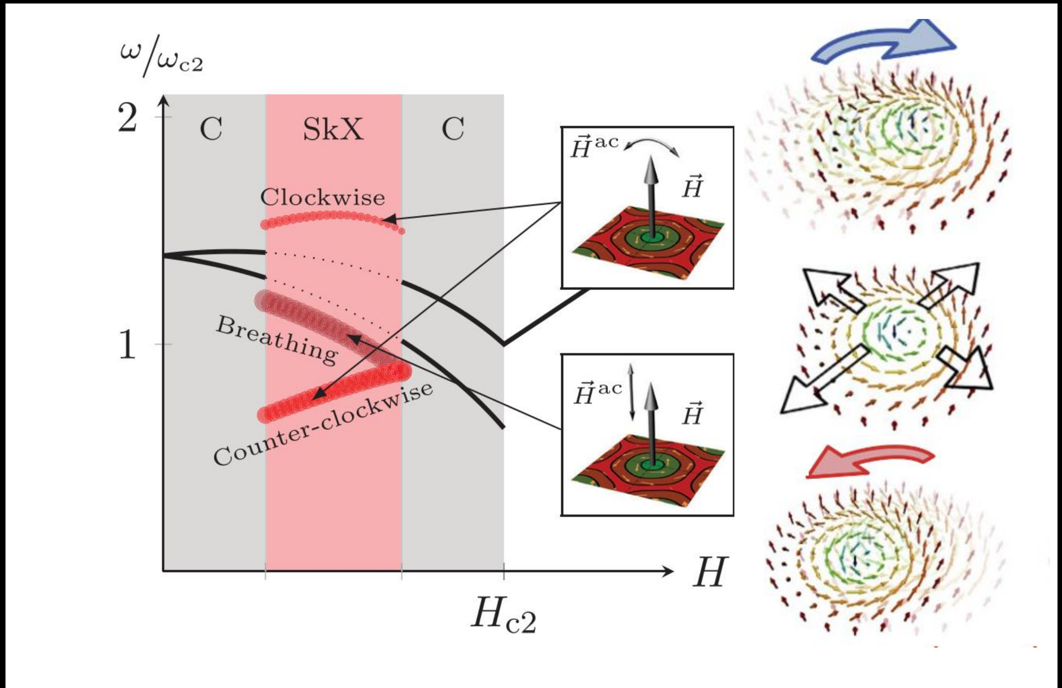
Magnons in ferromagnets vs. twisted background

Magnons in spatially varying effective magnetic field background

- **Effective magnetic field** varies across space
- Results in **band structure with natural gaps** *(like electrons in solids!)*



Schwarze..., Nat. Mat. **14**, 478 (2015)

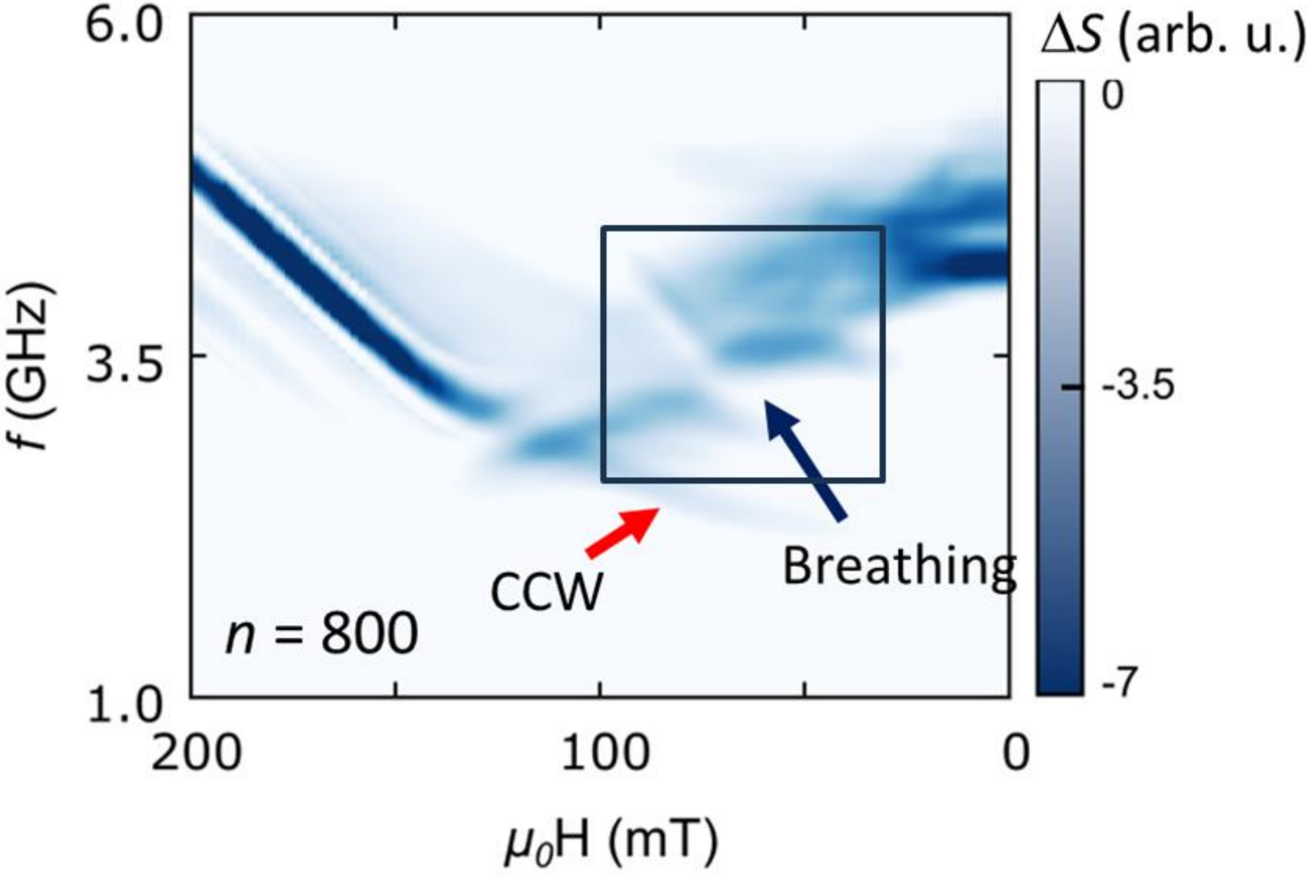
Clockwise (CW)

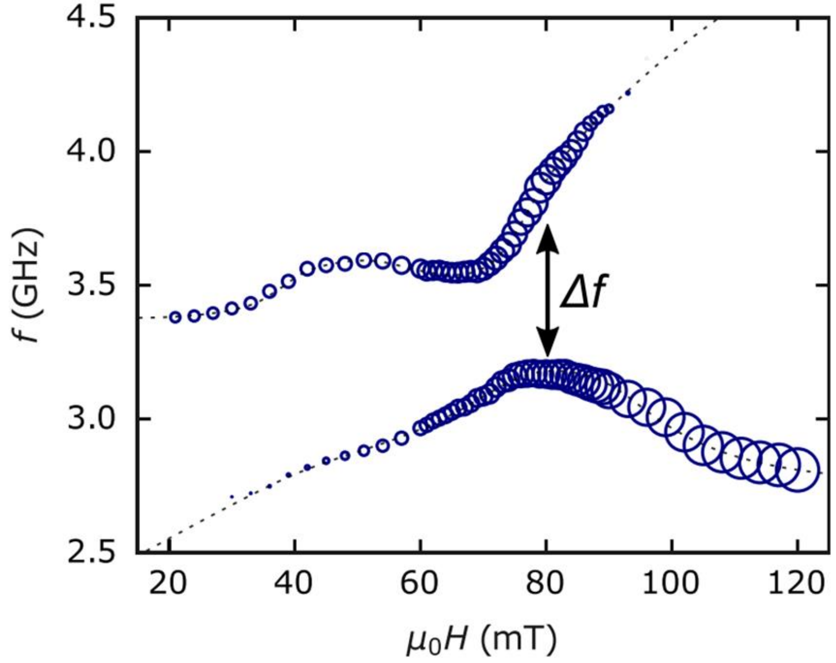
Breathing (Br)

Counterclock-wise (CCW)

Magnons in ferromagnets vs. twisted background

Experiment at 4 K, $H \parallel$ <001>

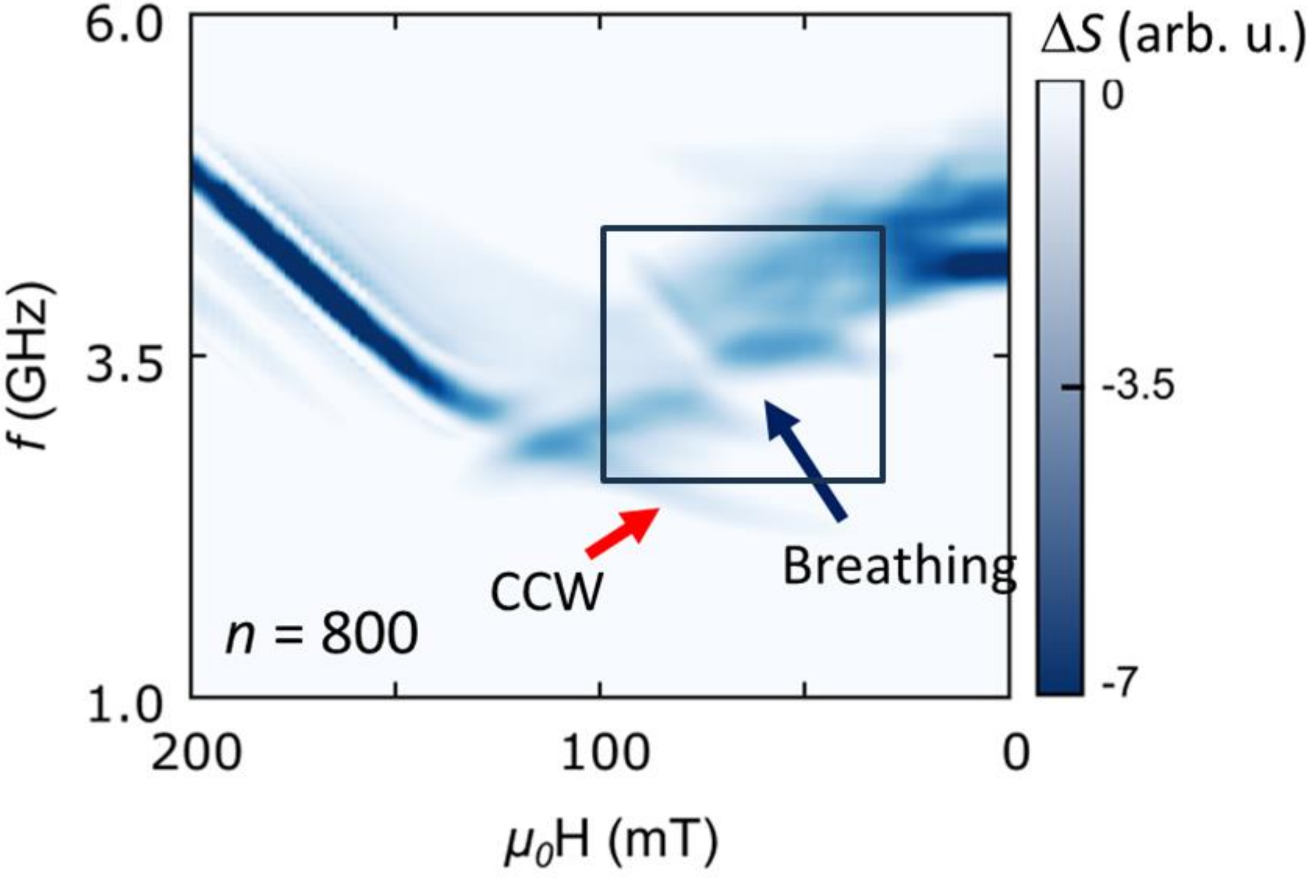




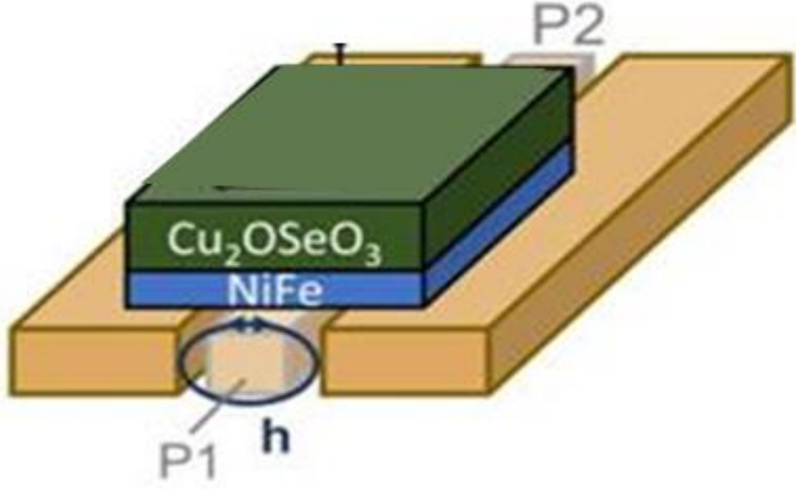
Aqeel, Sahliger, et al., *PRL* 2021

Magnons in ferromagnets vs. twisted background

Experiment at 4 K, $H \parallel$<001>



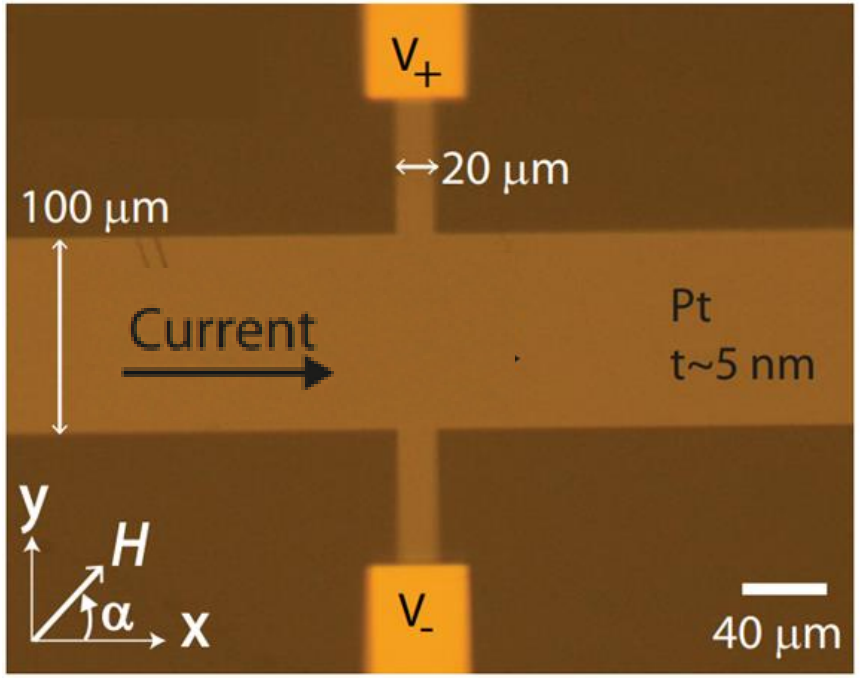
Aqeel, Sahliger, et al., *PRL* 2021



Lüthi, Flacke, Aqeel, *et al.*, APL 2023

Spin Hall magnetoresistance (SMR)

AC current → electrical response (SMR)



Pt / magnetic insulator interface

Electrical (SMR)

$$V_{\mathrm{SMR}} \propto I$$

Aqeel et al., PRB (2016, 2021)

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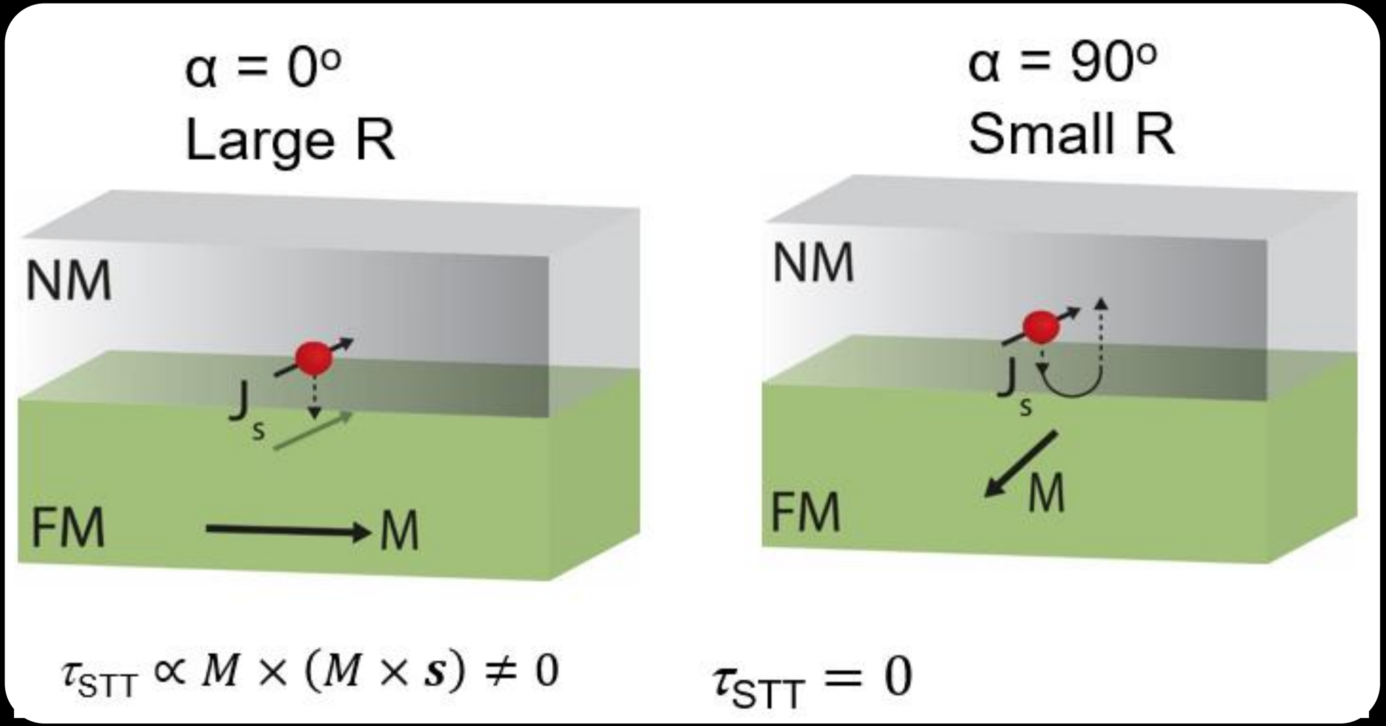
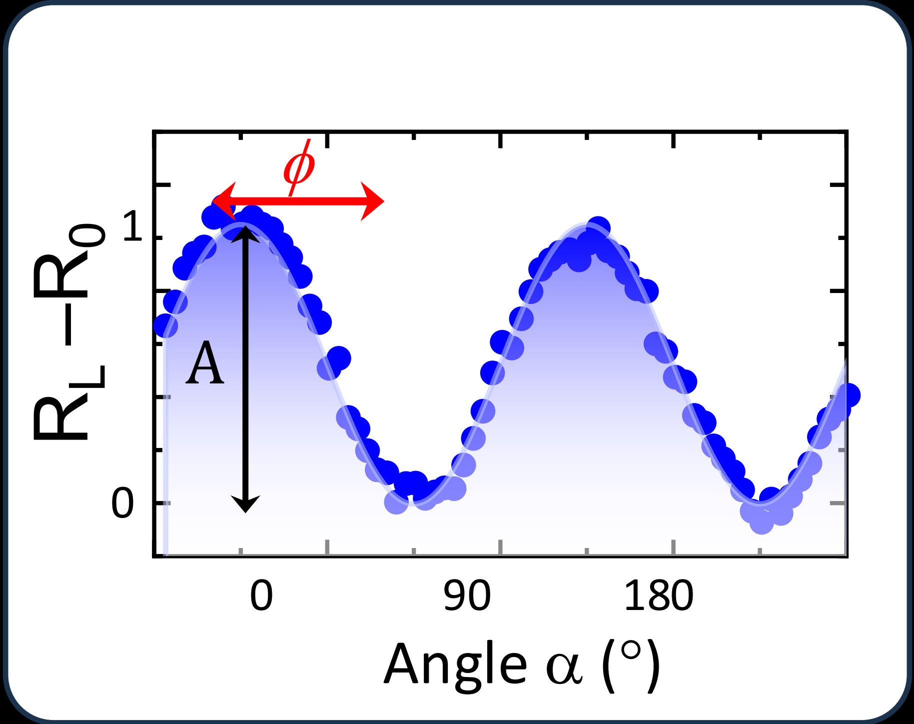
Spin Hall magnetoresistance (SMR)

Access to static magnetic configuration





SMR probes magnetic configuration via interfacial spin scattering

Chiral contribution to SMR amplitude

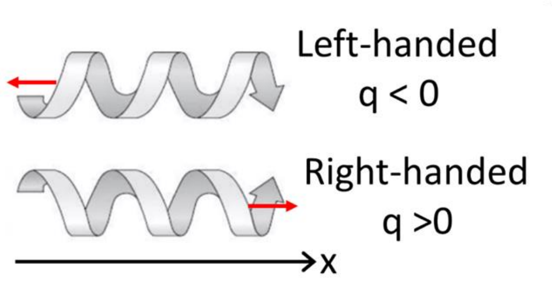
SMR amplitude = conventional + chiral

$$\text{conventional} \propto m_x\, m_y$$

$$\text{chiral} \propto \mathbf{m} \cdot (\nabla \times \mathbf{m})$$

$$\propto q$$

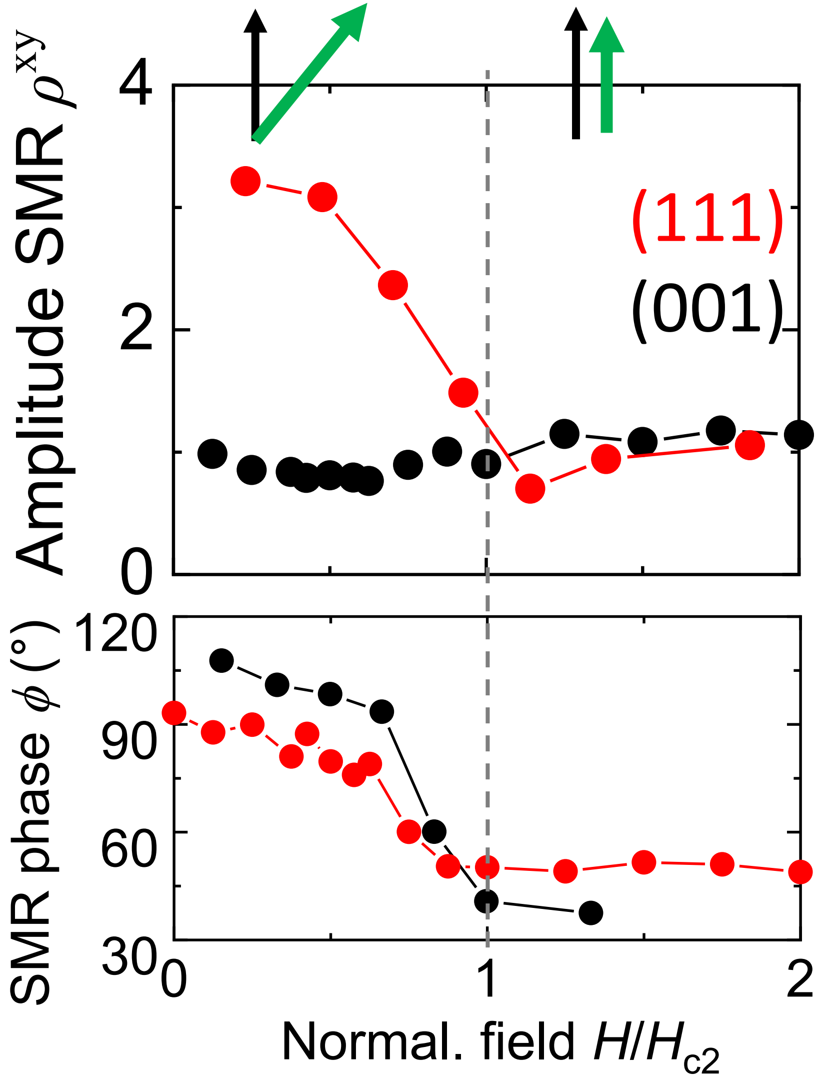
$q \rightarrow -q \Rightarrow \Delta\rho \rightarrow -\Delta\rho$



Chiral contribution to SMR amplitude

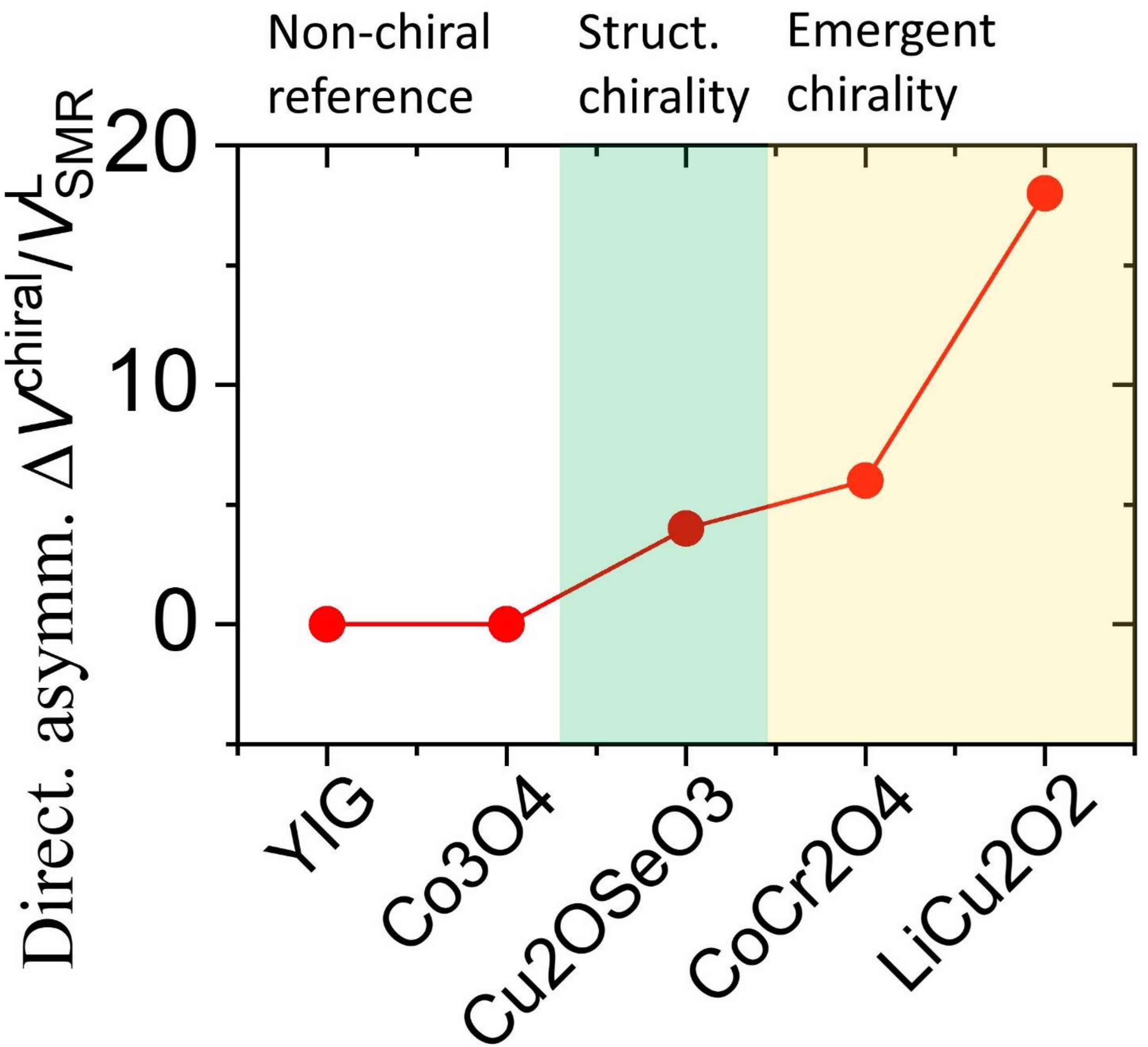
chiral ∝ q

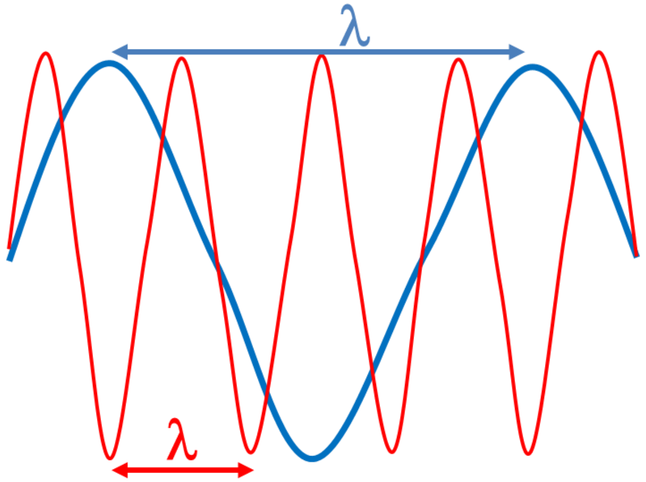
Transverse resistivity
(111) → strong chiral response
(001) → weak / suppressed



Amplitude changes strongly between (001) and (111)
→ consistent with symmetry-selected chiral contribution

SMR across different symmetry classes





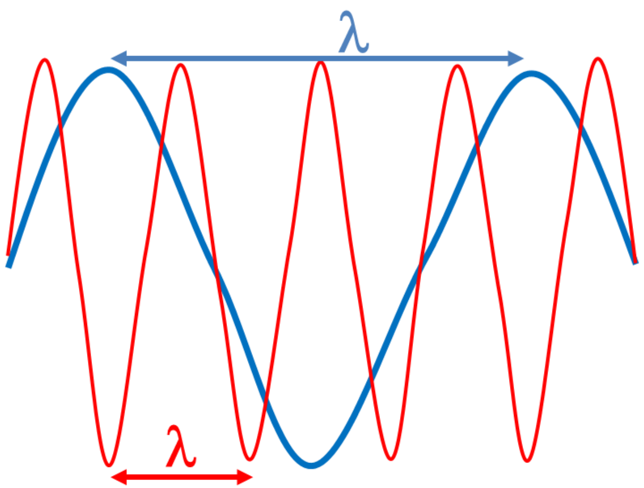
Summary

Magnons in Cu_2OSeO_3 better as we cool 🧊 😊

At **60 K**, damping $\boldsymbol{\alpha \approx 10^{-2}}$

At **4 K**, damping $\boldsymbol{\alpha \approx 10^{-4}}$

→ *longer-lived spin excitations at low T!*



What we need:

low damping + **smaller well-controlled twists**

***Colloquium*: Quantum properties and functionalities….**

Petrović et al., Rev. Mod. Phys. **97**, 031001 (2025)

Thanks to Collaborators

C. Back • C. Pfleiderer • H. Huebl (TUM)

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Florian Radu (HZB)

Matthias Kronseder (UR)

Maxim Mostovoy (RUG)

Sina Mehboodi
PhD

PhD

PhD